

**Before the
Federal Communications Commission
Washington, D.C. 20554**

In the Matter of)	
)	
Promoting Spectrum Access for Wireless)	ET Docket No. 14-166
Microphone Operations)	
)	
Expanding the Economic and Innovation)	
Opportunities of Spectrum Through Incentive)	GN Docket No. 12-268
Auctions)	

EX PARTE STATEMENT OF MARCUS SPECTRUM SOLUTIONS LLC

SUMMARY

This *pro se* statement addresses the spectrum efficiency allegations in the *Petition for Reconsideration* of Sennheiser Electronic Corporation in Docket GN Docket No. 12-268. In particular, it is shown that the limitations to efficiency claimed in the petition are not fundamental limits, but issues that can be addressed in normal engineering design.

INTRODUCTION

Marcus Spectrum Solutions LLC (MSS) is the consulting practice of Michael J. Marcus, Sc.D., F-IEEE, a retired FCC senior executive who worked at the Commission nearly 25 years in both the spectrum policy and enforcement areas. His qualifications are well known to the Commission¹. He was recently awarded the 2013 IEEE Communications Society Award for Award for Public Service in the Field of

¹ FCC Press Release “FCC Engineer Michael J. Marcus Honored by Institute of Electrical and Electronics Engineers (IEEE)” February 3, 2004, (http://hraunfoss.fcc.gov/edocs_public/attachmatch/DOC-243463A1.pdf)

Telecommunications.² He regularly publishes a blog, *SpectrumTalk*³, a comprehensive independent blog on spectrum policy and spectrum reform as well as writing a regular column on spectrum policy issues for *IEEE Wireless Communications Magazine*, published by the IEEE Communications Society - “the premier international forum for the exchange of ideas on communications technologies and information networking”⁴. As an adjunct professor of electrical and computer engineering at Virginia Tech, he teaches a course on spectrum policy for innovative wireless engineers and has lectured on spectrum policy at many universities in the US and abroad.

These comments do not necessarily represent the view of any client and are being submitted purely in the public interest. Indeed, MSS has no clients that have participated in these proceedings. These comments are motivated by the experience of Dr. Marcus during his FCC career and his interest in the maintaining US competitiveness in advanced wireless technology and efficiency in spectrum utilization.

SENNHEISER PETITION

The *Petition for Reconsideration* (“*Petition*”) of Sennheiser Electronic Corporation in Docket GN Docket No. 12-268⁵ addresses several issues dealing with wireless microphone (“wireless mic”) use of UHF spectrum. This statement only deals with three issues relating to spectrum efficiency of such use and possible theoretical limits. These issues are:

- a block of spectrum reserved exclusively for wireless mics
- the limitations of intermodulation in transmitters and receivers and

² <http://www.comsoc.org/about/memberprograms/comsoc-awards/telecom/bios>

³ <http://www.marcus-spectrum.com/Blog/Blog.html>

⁴ <http://www.comsoc.org/about/overview>

⁵ Petition for Reconsideration, Sennheiser Electronic Corporation, Docket GN Docket No. 12-268, filed September 15, 2014 (<http://apps.fcc.gov/ecfs/document/view?id=7522653857>)

- the limitations of information theory.

We fully agree with Sennheiser’s heading of their 3rd section of the *Petition*:

C. WIRELESS MICROPHONES ARE VITAL TO THE ECONOMY AND THE NATION’S PUBLIC LIFE

But the issue before the Commission is not whether to ban wireless mics. While wireless mic use was actually illegal until 2010⁶, the Commission has now stated explicitly that such a use of spectrum is in the public interest⁷ and no one now is questioning that.

The issue before the Commission is clearly stated in the *Petition*’s next section heading:

D. WIRELESS MICROPHONES NEED TWO BLOCKS OF CLEAN, RESERVED UHF SPECTRUM.

In this section it is clear that the petition requests spectrum access independent of any fees or costs and for the Commission to make a classic “command and control” decision on which technology is appropriate for now and for the future for wireless mics. As is clear from the history of “UHF Taboos” for TV broadcast spectrum, any such decision becomes a self-fulfilling prophecy for new technology because the wireless mic technology market will be totally isolated from marketplace forces that might bring in new more efficient technology.

⁶ <http://www.marcus-spectrum.com/Blog/files/4MHzWMPProp.html>

⁷ Revision to Rules Authorizing the Operation of Low Power Auxiliary Stations in the 698-806 MHz Band, *Report and Order and Further Notice of Proposed Rulemaking*, 25 FCC Rcd 643

At this writing Ms. Taylor Swift is famous for writing “music should not be free”⁸.

Is the music industry telling the Commission that for them, but virtually for no other commercial nonsafety spectrum user, spectrum should be free?

On the intermodulation issue the *Petition* states,

“As Sennheiser explained earlier in the proceeding: multiple transmitters, such as wireless microphones, are subject to a form of interference called “intermodulation” in which two or more desired signals combine in a receiver to produce undesired signals outside the spectra of the desired signals. This is a particular challenge with microphones, because they are constantly moving. The legacy solution has been to space units across a TV band in such a way that the intermodulation products caused by any combination of microphones and other TV band signals—these can number in the thousands—do not fall into the spectrum of another microphone signal. To achieve denser spacing, manufacturers must defeat intermodulation by making the microphones highly “linear,” which requires more battery power, which in turn adds bulk to body-worn units. Higher linearity also requires aggressive filtering to keep the signals isolated. Each of the techniques used to combat intermodulation adds significant cost.”⁹

On the information theory issue, the *Petition* states

“A third measure is not available: the principles of information theory say there is no way for each wireless microphone signal to occupy significantly less radio-frequency bandwidth without unacceptably impairing audio quality and or throughput latency (delay). Professional-grade microphones use analog modulation within the required 200 kHz bandwidth. An uncompressed digitally modulated microphone that delivers the same quality likewise requires about 200 kHz. Although a digital signal is more amenable to compression than an analog signal, compression necessarily adds latency, degrades audio quality, or both. This rules out compression for high definition professional applications such as recording and live performance. High audio quality is obviously essential; and a performer cannot tolerate more than a few milliseconds of delay over the entire loop from the microphone back to the monitor. The microphone must deliver the best possible signal, as all of the subsequent processing will tend to both degrade quality and add latency.”¹⁰

While there is *some* validity to each of the statements above, the presentation is misleading and issues are presented as fundamental limits rather than design issues to be addressed by engineers with a modern arsenal of technical design options for radio systems.

***Petition:* “WIRELESS MICROPHONES NEED TWO BLOCKS OF CLEAN, RESERVED UHF SPECTRUM”**

⁸ T. Swift, “For Taylor Swift, the Future of Music Is a Love Story”, *Wall Street J.*, July 7, 2014 (<http://online.wsj.com/articles/for-taylor-swift-the-future-of-music-is-a-love-story-1404763219>)

⁹ *id.* at fn. 3

¹⁰ *id.* at p. 5

Classic spectrum policy from the days of the Commission's 1920s predecessor to the 1980s used administrative law to allocated spectrum to various classes of users based on their needs and the amount of spectrum required with available technology. This policy is called "command and control" and is now generally avoided except for safety related services. Administrative law decisions on societal and market needs are generally slow compared to both changes in the market for services as well as technological changes that make spectrum use more efficient. Measurements by the Commission's Spectrum Policy Task Force (SPTF) and others have shown that even though most spectrum below 50 GHz is now allocated and licensed, most spectrum is actually lightly used even in major urban areas where spectrum demand is greatest¹¹.

SPTF also concluded

There are two basic situations that impact how spectrum efficiency can be improved: (1) situations in which all spectrum in an area is already assigned but not fully used; and (2) situations in which all spectrum is fully used. In the first situation, which can be referred to as "access limited," spectrum efficiency can be improved by increasing the access that other users have to the spectrum. In the second situation, which can be referred to as "throughput limited," efficiency can really only be improved by taking steps that permit existing users to provide greater information transfer rates. One could view the first situation as increasing capacity by putting in more pipes, and the second situation as increasing capacity within the existing pipes.¹²

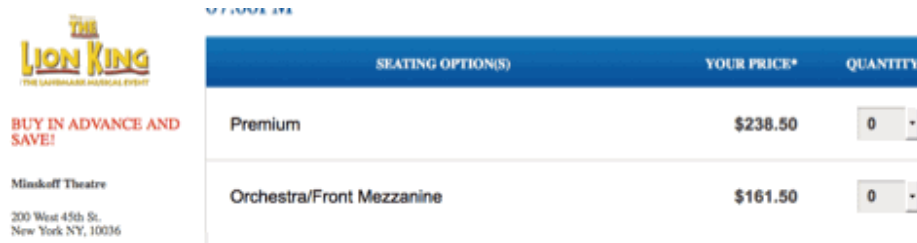
The approaches sought in the *Petition* to narrowly restrict access to "reserved UHF spectrum" to a class of users who are not ubiquitous in time and space and then declare outdated wideband FM as the prime technology flies in the face of both of these recommendations as well as most spectrum FCC policy of the past 2 decades. Creating new blocks of spectrum with such narrow eligibility requirements almost guarantees low

¹¹ Report of the Spectrum Efficiency Working Group, FCC . Nov. 2002
http://transition.fcc.gov/sptf/files/SEWGFfinalReport_1.pdf

¹² *id.* At p.16

spectrum utilization across our country.

Further, most of the wireless mic users seeking a nonmarketplace spectrum set aside are financially benefitting from such spectrum use. Consider this current ad for New York tickets to The Lion King, owned by Disney - a major FCC licensee already:



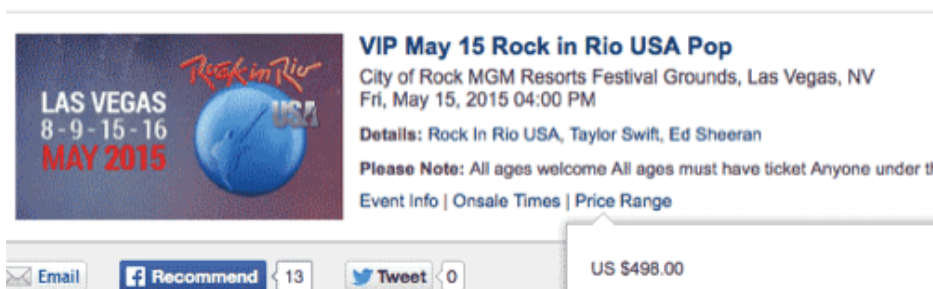
SEATING OPTION(S)	YOUR PRICE*	QUANTITY
Premium	\$238.50	0
Orchestra/Front Mezzanine	\$161.50	0

THE LION KING
THE LAYNELENE MUSICAL EVENT

BUY IN ADVANCE AND SAVE!

Minskoff Theatre
200 West 45th St.
New York NY, 10036

or this ad for a concert by Ms. “Music Should Not Be Free” Swift:



VIP May 15 Rock in Rio USA Pop
City of Rock MGM Resorts Festival Grounds, Las Vegas, NV
Fri, May 15, 2015 04:00 PM
Details: Rock In Rio USA, Taylor Swift, Ed Sheeran
Please Note: All ages welcome All ages must have ticket Anyone under the
Event Info | Onsale Times | Price Range

US \$498.00

Email Recommend 13 Tweet 0

If there is spectrum to be reserved for wireless mics, perhaps it should be a much smaller band reserved for small wireless mic users such as schools, conference centers and places of worship with modest audio systems. These small users only need a modest block of a 1 MHz or less with a capacity for about 10 mics and would otherwise incur significant transaction costs on any marketplace system. But larger users, e.g. Disney and major sports leagues, are much better capitalized and have present significant cash flows resulting from their wireless mic use. They can afford to pay for both marketplace access to spectrum and contemporary technology that uses that spectrum efficiently. Similarly, FCC licensed broadcasters are now used to paying for and knowing the value of their Part 73 spectrum, why should charging for Part 74 spectrum

be a surprise or a burden just because it was free during the analog TV era when it had no opportunity cost for others?

A large spectrum set aside for large wireless mic users would be a reversal of general spectrum policy trends of the past two decades after the Commission has already given most of the wireless mic users both an amnesty for past illegal use as well as a legitimization for future spectrum access. No one questions these two past actions. The issue now is should the Commission go further and give the same class of users access to spectrum on better terms than almost any other nonpublic safety users and should they lock this band into the use of an anachronistic technology isolated from marketplace forces and the technical innovation that permeates the wireless industry?

INTERMODULATION ISSUES

Intermodulation (IM) is a recurring problem in spectrum policy deliberations at FCC. It is the root cause of the Nextel/Public Safety interference issue as well as the long simmering issue between the Federal Aviation Administration and the Commission over possible interference from FM broadcast stations just below 108 MHz to the FAA's Instrument Landing System just above 108 MHz.¹³

Technically, IM is the combining of two or three strong wireless signals in a component of the radio system that has a flaw of "nonlinearity", that is it distorts the signal while processing it. As a result of this distortion, a new signal is unintentionally generated at a new frequency that is a mathematically related to the original frequencies.

The nonlinearity that causes IM can be either in the transmitter or the receiver.¹⁴

¹³ <http://www.marcus-spectrum.com/Blog/files/SiF11112.html>

¹⁴ In high power broadcast and land mobile transmitter systems, IM can also result from "rusty bolts", that is physical parts of the antenna system where currents are induced by the high power of the transmitter

Transmitter-generated IM seems to be the focus of the Sennheiser statement. But this only occurs when transmitters are in very close physical proximity as in the case of 2 wireless mics (for redundancy) on a major performer in a production or the case of two actors in a physical embrace. The number of wireless mics that are likely to be in close proximity with each other is a small fraction of the total population and improved transmitter design for those to prevent transmitter-generated IM is

A much more common, but not mentioned, problem comes from fixed receiver limitations, not performer-carried portable transmitter limitations where there are real size, weight and battery limitations. It is a truism in spectrum management that “transmitters do not use spectrum, receivers do”¹⁵. Receiver limitations often limit how intensely spectrum can be used, but new technology offers ways around these receiver limitations and are not addressed in the *Petition*.

Wireless mic receivers are fixed units in the theatre that receive the signals from the mics on the performers. As fixed units size, weight, and power consumption are not important issues. Improved linearity in receivers may increase their costs, but due to their fixed nature do not impose other burdens.

Automatic power control (APC) is used in many contexts in wireless systems and is mandated by the Commission in some contexts. Much of the receiver-generated IM is from “near/far problems”¹⁶, that is several wireless mics are close to the receiver’s antenna while one is further away and thus has a much weaker signal at the antenna. The strong signals can generate IM on the frequency of the weak signal if the frequencies are

antennas in close proximity. However, this type of IM does not occur in modest power wireless mic systems.

¹⁵ <http://www.marcus-spectrum.com/Blog/files/ReceiversSpectrum.html>

¹⁶ http://en.wikipedia.org/wiki/Near-far_problem

in the right mathematical relationship. In order to avoid this possibility, audio managers avoid using many frequencies just like the old NTSC “UHF taboos”¹⁷ limited UHF TV spectrum use to avoid interference caused by TV receiver limitations. APC could be used to decrease this problem although would require some additional electronics in the transmitter. But in this day and age of microelectronics this is not a heavy burden.

Virtually all wireless mics today use “wideband FM” technology invented by radio pioneer Maj. Edwin Howard Armstrong and patented on December 26, 1933.¹⁸

- This is the same historic technology that FCC has been trying to phase out of Part 90 for both public safety users and nonpublic safety users for two decades as part of narrowbanding¹⁹.
- This is the technology used in the original AMPS/TAC 1st generation cellular system that was phased out in 2G cellular.
- This is the same technology formerly used for audio in analog television.
- This is the same technology once widely used in the satellite industry but now generally replaced by digital technology.
- This is the same technology still used in FM broadcasting but now supplemented with digital technology known as “HD Radio”.
- This is a clearly dated technology that has been historically important but has been or is being replaced in most modern radio systems.

A key cause of IM in wireless mic systems is their use of frequency division

¹⁷ FCC/OET, TM 87-2,

http://transition.fcc.gov/Bureaus/Engineering_Technology/Documents/reports/TM87.pdf

¹⁸ U.S. Patent 1,941,066 : "Radio Signaling System"

¹⁹ <http://transition.fcc.gov/pshs/public-safety-spectrum/narrowbanding-faq.html>

<http://www.narrowband.us/>

<http://wiki.radioreference.com/index.php/Narrowbanding>

multiple access (FDMA) FM. A time division multiple access (TDMA) system, such as the one used in 2G GSM cell phone since 1987²⁰, would avoid all IM since transmissions would be separated in time. OFDMA/LTE-like technology is also TDMA-like in nature and could be used to avoid IM.

INFORMATION THEORY ISSUES

The “information theory” discussion in the Sennheiser Petition is also misleading. Actually it is a common rhetorical device used in FCC filings: describe a “strawman” system design that puts your party in the best possible light and his opponents in the worst possible light and then generalize that the design is the only possible design or has characteristics that are inevitable in any other design. The focus of the “information theory” discussion in the Petition is to try to rationalize that wideband FM is the only possible modulation for wireless mics as any digital approach would appear to need more spectrum.

As fn. 5 explains correctly, professional quality wireless mics for musical productions, not necessarily for broadcast vocal commentary, need a digital sample rate of 44,100 times per second, same as CDs. This is because of the assumption that listeners can hear sound up to 20 kHz and the Nyquist–Shannon sampling theorem²¹ requires a sampling rate of at least twice that. Thus the conventional 44,100 times per second makes great sense. This technology is called pulse code modulation (PCM)²² and was first proposed in the 1920s. However, Sennheiser then tries to extrapolate that into a 200 kHz minimum spectrum requirement using some unstated assumptions.

²⁰ http://www.gsmhistory.com/who_created-gsm/

²¹ http://en.wikipedia.org/wiki/Nyquist%E2%80%93Shannon_sampling_theorem

²² http://en.wikipedia.org/wiki/Pulse-code_modulation

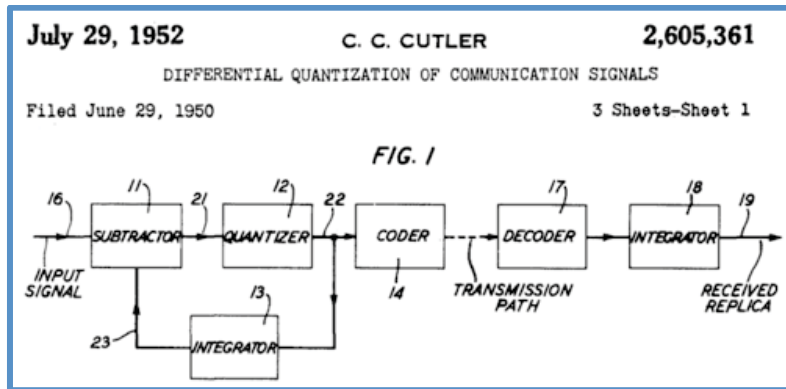
True, many wireless mic users have a time latency requirement, but the specific requirement and its justification are not stated. Although today's wireless mics are virtually all analog, many theatres, concert venues, and outdoor music productions today use "digital mixers"²³ to mix the sound from multiple sources and process the sound before it is amplified in analog amplifiers. The analog-digital (A/D) and digital-analog (D/A) conversions in these digital mixers introduced delay as does some of the digital filtering operations available in the mixers to filter and manipulate the audio – especially in rock concerts. The audio industry does not generally use digital inputs to these mixers, resulting in multiple A/D and D/A conversions, each adding latency. The burden for controlling latency should not be placed entirely on the wireless mic part of an audio system, it is a system wide problem needing a systems approach.

The type of voice compression used in cell phone networks was optimized for low bit rate to maximize spectrum use in large networks. In cell phone and telephony systems users are tolerant of latency delays of up to 100 ms. So the designers traded off latency for low bit rate. But there are not the only possible tradeoffs!

²³ Some examples:

http://usa.yamaha.com/products/live_sound/mixers/digital-mixers/
<http://www.behringer.com/EN/Category/Mixers.aspx?s=G600>
<http://www.presonus.com/products/mixers>

One way to decrease bit rate without introducing latency is to use differential pulse code modulation (DPCM)²⁴. As shown in the patent diagram below, this is not new technology!



Such a system could use the present 44,100 times per second sampling rate but much less than the 20 bits/sample now used in CDs since only the difference between the adjacent samples needs to be sent. While there is power in audio signals up to 20 kHz, most of the power is in the lower frequencies enabling few bits per sample for the difference. A variant of DPCM, Adaptive differential pulse code modulation²⁵ (ADPCM) has been known since the early 1970s and gets additional efficiency by varying the step size used to convey the difference between samples. (Note the fact that both DPCM and ADPCM have their own Wikipedia pages shows that these are not esoteric technologies known only to information theory academics.)

All Sennheiser has shown in their “information theory” discussion is that an implementation based on the PCM sampling used in CDs would be no more efficient than the traditional, but dated, wideband FM given some unspecified and unproven time latency requirement. The PCM system used in CDs was optimized for CDs where there

²⁴ http://en.wikipedia.org/wiki/Differential_pulse-code_modulation

²⁵ http://en.wikipedia.org/wiki/Adaptive_differential_pulse-code_modulation

are very different constraints than for a radio based system. It should not be surprising that it is not a good choice for use in digital wireless mics. But other technical options are available if FCC creates the right incentives for them.

OTHER TECHNOLOGIES NOT CONSIDERED

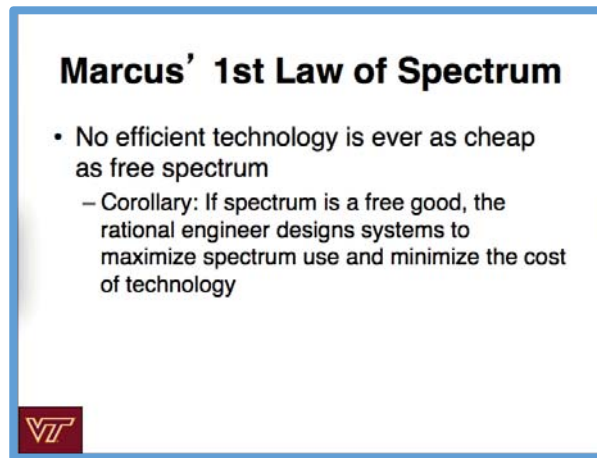
A recent white paper²⁶ by the IEEE Communications Society reviews the technologies under consideration for 5G cellular to increase spectrum efficiency by more than an order of magnitude. Not all the options considered in the white paper are applicable to the wireless mic context, but many of them such as MIMO, improved modulation and frequency reuse are likely to be applicable. A similar list of contemporary spectrum technologies is in a recent paper on new directions for Wi-Fi.²⁷

²⁶ IEEE Communications Society Special Interest Group Cognitive Radio in 5G, “White Paper - Novel Spectrum Usage Paradigms for 5G”, Nov. 2014 (http://cms.comsoc.org/SiteGen/Uploads/Public/Docs_TC_CN/WhitePapers/2014_11_White_Paper_Spectrum_Paradigms_v1.0.pdf)

²⁷ W. Sun *et al.*, “Wi-Fi Could be Much More”, *IEEE Comm. Mag.*, Vol. 52, No. 11, p. 22-29 (Nov. 2014)

CONCLUSIONS

Dr. Marcus teaches a course in spectrum policy at Virginia Tech and has lectured on the topic at many distinguished universities. Below is a slide from his standard introductory presentation on spectrum policy.



US wireless mic users and their equipment suppliers are accustomed to spectrum as a “free good” - even if their use was generally illegal until 2010. While the history of how this happened, “who knew what when”, and whether there was any criminality involved is now “water over the dam”, FCC policy has consistently and strictly limited “free spectrum” in the past 20 years. It has also either encouraged or required improved spectrum efficiency using contemporary technology – not technology developed in the 1930s!

While the *Petition* alleges to show that theory proves no spectrum efficiency improvements are possible for wireless mics, in reality it puts up one straw man digital system and then shows that has no efficiency advantages – extrapolating that to any other implementation. The petitioner and its colleagues in the wireless mic community have no incentive to make a quantum jump in efficiency as long as FCC looks like it might

reverse recent spectrum policy trends and give them a spectrum set aside of several MHz. Both the CMRS community and the Wi-Fi community have made astounding progress in spectrum efficiency in the past decade. While the requirements of wireless mics with respect to time latency are somewhat different than the requirements in the other two communities, that does not mean that the technical building blocks of modern wireless systems do not apply to wireless mics system also.

In general, spectrum users with incomes resulting directly or indirectly from spectrum use have had to pay for spectrum access. Prof. Coase explained in his classic 1959 paper²⁸ how economic forces are better at making spectrum use and technology decisions than regulators – a policy that FCC has generally followed for the past 2 decades. Sennheiser and others in the wireless mic community are asking that FCC return to the now discredited “command and control” style of spectrum policy to let them continue to use outdated wideband FM and to discourage new entrants with more efficient technology. FCC should firmly reject this viewpoint and use marketplace forces to favor technical efficiency.

/s/

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²⁸ R. H. Coase, The Federal Communications Commission, *J. Law Ec.*, Vol. 2 (Oct., 1959), pp. 1-40

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